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When It All Began:
The 1936 Tinbergen Model Revisited

by
Geert Dhaene
and
Anton P. Barten

Reprinted from Economic Modelling, Vol. 6,
Number 2, 1989



Reprint Series
no. 9

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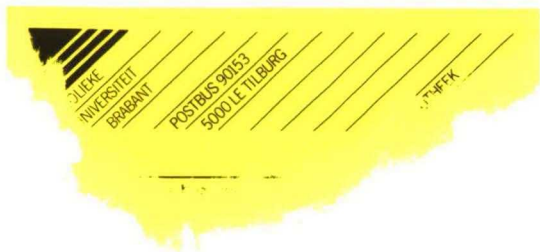
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When it all began

The 1936 Tinbergen model revisited

Geert Dhaene and Anton P. Barten

The first empirical macroeconomic model was constructed by Tinbergen in 1936 for the Netherlands economy. The paper discusses the intellectual and political context within which it emerged, its major characteristics, structural specification, dynamic properties and use for policy analysis. It also re-estimates the model with current estimation techniques. It appears that given the short sample (11 years) simultaneous inconsistency does not make itself felt. The model is a rather refined, dynamic, policy-oriented, empirical, macroeconomic model for an open economy. Since the 1936 model progress has no doubt been made; but less than might be thought.

Keywords: Macroeconomic model; The Netherlands; Macroeconomic policy

To assess the distance covered in a discipline it is natural to look back to its beginnings. In the case of empirical macroeconomic modelling the beginning is clear and unambiguous: the model built by Tinbergen in 1936 for the Dutch economy. It emerged almost out of nothing and began a tradition of macroeconomic modelling which has continued until today and generates a multitude of models of an enormous variety of scope, purpose and complexity.

It is our purpose to take a close look at this 1936 Tinbergen model. First, the political and intellectual contexts in which it developed are briefly sketched. Then the main characteristics of the model will be presented. Next, its structural equations are reviewed. It is of some interest to see how Tinbergen went about solving his 24-equation model in order to trace out seven alternative policy scenarios (the topic of the fifth section). We then turn to a description of the dynamic properties of the model. The model reveals these properties in its impact and interim multipliers, some of which are presented and discussed in the seventh section.

The seven alternative policy scenarios, together with their consequences, are taken up in the eighth section. The 1936 model was the first of its kind. In the concluding section its direct successor, the Tinbergen 1937 model and some other models that were built

before World War II are reviewed. The concluding remarks are followed by two appendices dealing with estimation aspects.

The context

Tinbergen presented his model at the 1936 annual meeting of the Dutch Association for Economics and Statistics. Since 1893 this association of professional economists had organized its annual meeting around a theme introduced by three or more speakers, usually from different backgrounds. The 1936 theme was the recovery of the domestic economy, with or without government action, and possibly even without an improvement in exports.

The theme implicitly referred to the deterioration in the Dutch economic situation since 1929. The Depression had initially been less severe than in the USA; but in contrast to countries like the UK and the USA there was still no sign of recovery in the mid-1930s. By 1936 Dutch international trade, historically the major source of Holland's prosperity, had dwindled to one-third of its 1929 level. With a conviction more deeply rooted in ethics than in economic reasoning, the government stuck to the gold (exchange) standard to which the country, together with the UK, had returned in 1925. It tried to cope with the overvaluation of the Dutch guilder by a politically painful downward adjustment of domestic prices, wages and costs.

Tinbergen approached the theme set by the Association board by considering several alternative policy scenarios: P, a three-year investment programme; Q, the limitation of imports of finished consumer goods; R, an increase in labour productivity combined

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with price reduction and no increase in investment; R' , a reduction in prices without changes in labour efficiency and without wage reductions; S , a non-recurrent reduction in the wage rate; and T , a devaluation of the guilder, taking into account reprisals by foreign countries. To study the consequences of these policy alternatives he constructed a model, a system of 24 empirically verified equations, which was amply documented in his memorandum for the meeting – see Tinbergen [11].

The idea of building a model and using it for policy analysis was without precedent. The Great Depression was the Great Boom for business cycle theory, but there was little in its mainstream that suggested anything like a model. In his review of business cycle analysis Haberler [4] briefly mentions (as a kind of afterthought in a footnote at the end of Part I) the work of Frisch and Tinbergen as examples of the dynamic, mathematical approach that he considered virtually unfeasible.

Frisch and Tinbergen were the nucleus of a small group (Kalecki was also a member) within the newly formed Econometric Society that applied the theory of difference and differential equations to the analysis of the phenomenon of the business cycle. In his well known contribution to the Cassel *Festschrift* Frisch [2] presented a 'macrodynamic' system of equations able to generate cycles of realistic periodicity in response to non-periodic impulses. For the parameters of this system he used rough guesses, but he believed 'that it [would] be possible by appropriate statistical methods to obtain more exact information about them'. He thought, indeed, 'that the statistical determination of such structural parameters [would] be one of the main objectives of the economic cycle analysis of the future'.

In a 1935 *Econometrica* survey of recent quantitative business cycle theory Tinbergen went one step further. He presented a kind of cobweb model for national consumption which he fitted by a variant of least squares to quarterly data for FRGermany and the USA. This was the very first example of an empirically verified dynamic (business cycle) model. It was not, however, a useful tool for policy analysis and can hardly count as a predecessor of the 1936 model. In another paper Tinbergen [10] presented a more refined model which was, however, not estimated. Its specification resembles that of the 1936 model, the main characteristics of which are discussed in the next section.

Main characteristics of the 1936 Tinbergen model

The 1936 Tinbergen model appeared in the papers of the 1936 meeting of the Dutch Association for

Economics and Statistics in Dutch. An English translation of it was not published until 1959.

The 1936 model consists of 24 equations. Compared to several current modelling projects it is small but rather sizable for a beginner. As Tinbergen [16] points out, its size was minimal considering the desire to distinguish between two social groups (labour and others), two kinds of goods (consumer and investment goods), two kinds of use for non-labour income (consumption and saving), two points in time at which to measure this income (moment of earning and that of actually receiving), two stages of processing goods (finished goods and raw materials) and two economies (The Netherlands and the rest of the world).

Table 1 gives the variables of the model with their original symbols. Their description reflects the desired distinctions. The original memorandum supplied the observations for all variables for 1923–33. In some cases values are given for 1934 and 1935, while it was possible to reconstruct some values for 1921 and 1922 used in lags. The data came from various sources, mostly from the Central Bureau of Statistics of which Tinbergen was an employee at the time. He constructed several of the series himself. It is important to realize when going over the table that the system of national accounts had not yet been established. We note the absence of government related variables like taxes or government expenditures. Note also the absence of investment, though 'means of production' comes close to that concept. Monetary and financial variables, even the rate of interest, are also missing. The model is concerned with the real sector only.

The nominal values are expressed in units of 17.54 million guilders, which is 10% of the average wage bill over the period 1923–33. All prices, except p_w , have base 1923–33 = 100. This means that all quantities have as unit the quantity whose average value for the 1923–33 period was 17.54 million guilders.

Table 1 also indicates which variables are endogenous and which are exogenous. The trend, all import prices as well as the world price level, p_w , are exogenous. Moreover the volume of world exports and income from investment abroad are exogenous. Otherwise said, the international environment is taken as given. Observe that exports, value, volume and price, are endogenous.

To the 24 remaining variables – the endogenous ones – correspond 24 structural equations, summarized in Table 2. The coefficients of the equations are taken from a corresponding table in the original memorandum, except for the coefficient of the linear trend t and the intercepts. The trend coefficients could be read off the graphs in the Tinbergen memorandum. The intercepts were calculated by us.

The presence of a trend in so many equations reveals

Table 1. The variables.

Description	Symbol	Unit	Average value 1923-33	Nature
Trend	t	1928 = 0	0	Exogenous
Prices				
Daily wage rate	l	1923-33 = 100	100	Endogenous
Cost of living	p	1923-33 = 100	100	Endogenous
Price of means of production	q	1923-33 = 100	100	Endogenous
Export price at the border	p_A	1923-33 = 100	100	Endogenous
Import prices at the border				
Finished consumer goods	p'_A	1923-33 = 100	100	Exogenous
Finished means of production	q'_A	1923-33 = 100	100	Exogenous
Materials for consumer goods	r'_A	1923-33 = 100	100	Exogenous
Materials for means of production	s'_A	1923-33 = 100	100	Exogenous
World price level	p_w	1926-30 = 100	94	Exogenous
Physical quantities				
Employment, total (in days)	a	1923-33 = 100	100	Endogenous
Employment in investment industries	b	As that of a quantity	24	Endogenous
Total output	u	whose average value over	335	Endogenous
Output of consumer goods for domestic consumption		1923-33 was		
Output of export goods	u_A	17.54 million guilders	249	Endogenous
Quantity imported			88	Endogenous
Finished consumer goods	u'_A		59	Endogenous
Finished means of production	v'_A		13	Endogenous
Materials for consumer goods	x'_A		41	Endogenous
Materials for means of production	y'_A		13	Endogenous
Volume of world exports	z	1929 = 100	85	Exogenous
Nominal values				
Total wage bill	L	17.54 million guilders	100	Endogenous
All other income, when paid out	E	17.54 million guilders	185	Endogenous
All other income when earned, plus undistributed profits	Z	17.54 million guilders	194	Endogenous
Consumption out of other income	E'	17.54 million guilders	136	Endogenous
Saving out of other income	E''	17.54 million guilders	32	Endogenous
Exports	U_A	17.54 million guilders	88	Endogenous
Consumption	U'	17.54 million guilders	235	Endogenous
Imports				
Finished consumer goods	U'_A	17.54 million guilders	58	Endogenous
Finished means of production	V'_A	17.54 million guilders	13	Endogenous
Materials for consumption goods	X'_A	17.54 million guilders	41	Endogenous
Materials for means of production	Y'_A	17.54 million guilders	13	Endogenous
Income from investment abroad	I	17.54 million guilders	28	Exogenous

the intention to construct a business cycle model. The long-run development was not specified and was simply represented as a trend. It was realized that estimating the trend coefficients along with the other coefficients was equivalent to first detrending the series and then estimating the coefficients of these variables – see Frisch and Waugh [3].

A number of the coefficients of the structural equations were fixed *a priori*; the others were estimated. Tinbergen [10] was aware of the fact that among the numerous multiple regression techniques available at the time none was adequate because they all basically assumed that only one of the variables was random. As a way out he applied least squares with the coefficients divided by the (overall) correlation coefficient. In the case of bivariate regression this procedure removes the

asymmetry between regressand and regressor. For multiple regression this is, of course, not the case. Since many of the equations display a good fit, this procedure does not lead to large differences from least squares.

In Appendix 1 we report the re-estimation of the system by least squares. Standard errors, coefficients of determination and Durbin-Watson statistics are also given there. One conclusion is that recalculation by and large confirms the Tinbergen results. The same appendix also presents the results of consistent, instrumental variables estimations. These are also rather similar to the values obtained by Tinbergen. Appendix 2 reports on two more formal tests of the seriousness of least squares inconsistency. Generally speaking, the test outcomes do not reveal that this inconsistency is an important issue.

Table 2. The structural equations.

$l - l_{-1} = 0.27(p_{-1} - p_{-2}) + 0.16a - 16.28$	(1)
$p = 0.04p'_A + 0.15(r'_A + 2l - 6t) + 0.08u + 24.24$	(2)
$q = 0.74q'_A + 0.16(s'_A + 2l - 6t) + 0.16t - 22.47$	(3)
$p_A = 1.28p_w + 0.04(r'_A + 2l - 6t) - 32.18$	(4)
$u = u_A + u' - 2$	(5)
$u_A = z + 2.23(0.75p_w + 0.25p_{w-1}) - 1.26p_A + 1.71t - 82.78$	(6)
$u' = L + E' - 2.49p + 262.50$	(7)
$v'_A + 3y'_A = 0.51Z_{-1} + 2.93t - 48.10$	(8)
$a = b + 0.20u'_A + 0.98x'_A - 0.28t + 23.87$	(9)
$y'_A = 0.69b + 0.27t - 3.56$	(10)
$u = 1.72u'_A + 4.35x'_A + 54.82$	(11)
$x'_A - 0.71u'_A = -0.42p + 0.39p'_A + 0.97t + 2.58$	(12)
$y'_A - v'_A = 0.86(q'_A - q) - t - 0.813$	(13)
$L = a + l - 100.2$	(14)
$Z = l + U' + U_A + 3b + 0.71q - L - X'_A - U'_A - Y'_A$ $+ 0.24(s'_A - s'_{A-1}) + 0.38(r'_A - r'_{A-1}) + 0.47(p'_A - p'_{A-1}) + 0.3(Z - Z_{-1}) - 80.95$	(15)
$E = 0.48Z + 0.20Z_{-1} + 52.47$	(16)
$E' + E'_{-1} = 0.26E_{-1} - 1.8t - 244.07$	(17)
$E'' + E''_{-1} = 1.74E_{-1} + 1.74t - 244.39$	(18)
$U_A = u_A + 0.88p_A - 87.48$	(19)
$U' = L + E'$	(20)
$U'_A = u'_A + 0.58p'_A - 58.89$	(21)
$V'_A = v'_A + 0.13q'_A - 12.99$	(22)
$X'_A = x'_A + 0.41r'_A - 41.55$	(23)
$Y'_A = y'_A + 0.13s'_A - 13.13$	(24)

The model counts nine identities. Equations (5) and (20) are additive. Equations (7), (14), (19) and (21)–(24) are linearized multiplicative, linking the value, volume and price of the various concepts. The linearization is around the sample mean. The approximation errors are minor. The small number of additive, accounting identities is another symptom of the fact that the model predates the system of national accounts.

As far as the contemporaneous interdependence is concerned it appears that Equations (17) and (18) are prerecursive, while Equations (19), (20), (21), (22), (23), (24) and (15) followed by (16) are post-recursive. Equations (19)–(24) generate values which appear in Equation (15), determining other income, which appears in Equation (16). The block of volume and price equations is fully interdependent. Equation (1), the wage formation equation, linking the wage rate, l , and employment, a , is crucial to this interaction.

Structural equations

In this section the various structural equations will be reviewed. They are taken up block by block.

Consumption

The equations discussed under this heading are (2), (7), (16), (17), (18) and (20). The explanation of private consumption is in terms of expenditure. Equation (20)

$$U' = L + E'$$

is an accounting identity. It expresses the idea that total consumer expenditure, U' , is the sum of consumption outlays by workers, L , and those by other-income earners, E' . However, this equation also reflects a behavioural assumption: that all labour income is spent on consumption. This assumption is not testable because E' has been calculated as $U' - L$.

The other behavioural assumptions about consumption concern the relation between consumption out of other income, E' , and that income when paid out, E , and between E and other income as earned, Z . The first relation is expressed in Equation (17) as

$$E' + E'_{-1} = 0.26E_{-1} - 1.8t + 224.07$$

Here a two-year moving average in consumption by

other-income earners is made dependent on other income earned the year before. The term in t represents a trend. The implied marginal propensity to consume is 13%. The equation was estimated (17a) as

$$E'_{t+1} + E' = 0.26E - 1.8t + \text{intercept}$$

for the period 1923–32 because of lack of a value for E' for 1934. The R^2 is 0.939. There is no autocorrelation in the residuals. The moving average on the lefthand side is slightly awkward because it causes current consumption to depend negatively on past consumption.

A marginal propensity to consume of 13% seems to be on the low side, considering the fact that farmers and small businessmen are among the other-income earners. It might reflect the possible underestimation of consumption by this group resulting from the overestimation of consumption by workers, who were *a priori* attributed a marginal propensity to consume of unity. Moreover, the income concept used here is that of income before taxes.

Analogous to Equation (17) there is the savings equation (18):

$$E'' + E'_{-1} = 1.74E_{-1} + 1.74t - 261.03$$

where E'' is savings out of other income. For estimation the time subscript was shifted; but given a 1934 value for E'' the full sample period 1923–33 could be used. The R^2 is 0.862. The estimated coefficient of E_{-1} turned out to be 1.65 but this value was replaced by 1.74 to preserve the identity $E = E' + E''$.

The way in which other income paid out, E , depends on other income when earned, Z , is expressed in Equation (16) by

$$E = 0.48Z + 0.20Z_{-1} + 52.47$$

with $R^2 = 0.991$. Obviously, not all other income is being paid out. About 32% appears to be retained.

Combining Equations (16), (17) and (20) we may conclude that other income, Z , affects consumption expenditure very marginally and with a considerable delay.

Using Equation (20) we can rewrite Equation (7),

$$u' = L + E' - 2.49p + 262.50$$

as

$$u' = U' - 2.49p + 262.50$$

(Equation (7a)), with p being the cost of living. It appears from (7a) that it is a linearization of a value–volume conversion. The structural volume–price elasticity is -1 due to the absence of structural price effects in the determination of U' .

The cost of living is explained by Equation (2):

$$p = 0.04p'_A + 0.15(r'_A + 2l - 6t) + 0.08u + 24.24$$

with $R^2 = 0.978$. In this equation p'_A , the price of imported finished consumer goods, represents competition between locally produced and imported consumer goods. The second term is a cost term, with r'_A being the import prices of the raw materials going into the production of consumer goods, while l is the wage rate. The term with t represents productivity increase. Its coefficient is set *a priori*. The coefficient 2 of l reflects the assumption that wages constitute two-thirds of production costs. Finally, the term with u , total output, expresses the nature of the equation as a price setting rule for the suppliers. Note that the variable in question is not u' , consumption. In current parlance the presence of u in such a price equation would be justified as a tension effect.

Investment

Table 1, the list of variables, does not include fixed capital formation or changes in stocks. Instead, the term 'means of production' is used. However, Tinbergen presents

$$v'_A + 3y'_A = 0.51Z_{-1} + 2.93t - 48.10$$

as the investment equation, (8). On the lefthand side is the sum of imported means of production, v'_A , and domestically produced means of production.

The latter are assumed to require imported raw materials, y'_A , for about one-third of their value in the base period. This explains the *a priori* fixed value of 3 for the coefficient of y'_A . Equation (8) follows a profit explanation of investment, which is a recurring feature in most later models for the Dutch economy – see Barten [1]. The rate of interest was not able to add to the explanation. It had not varied much over the sample period, while capital costs were a relatively unimportant part of total investment costs. According to Tinbergen [9], little unambiguous empirical evidence was found in favour of the acceleration principle, which was popular with the business cycle analysts of the time. The ability to raise finance for new investments can be linked to the price of shares. These are supposed to reflect profits, Z . This then explains the presence of Z_{-1} as an explanatory variable next to the usual explanation of investment by profit expectations as generated by actual profits. The strong positive trend captures gradual technological and structural changes. The equation has a reasonable fit: $R^2 = 0.887$.

The price of means of production, q , is determined in Equation (3) as:

$$q = 0.74q'_A + 0.16(s'_A + 2l - 6t) + 0.16t - 22.47$$

Competition with imported finished means of production is represented by their price, q'_A . Its effect is much stronger than in the case of Equation (2), the

consumption price equation. This is natural. Moreover, imported finished means of production are on average a quarter of total investment, so for that reason their price, q'_A , has a place in Equation (3). The cost term is of about the same type and importance as in Equation (2), except that here s'_A , the price of imported raw materials for means of production, appears. An extra trend is added, which somewhat corrects for the effect of productivity increases in the costs term.

Exports

In a model which is meant to study, *inter alia*, the effects of devaluation, the presence of an export equation depending on foreign and domestic prices is natural. This is the case for the equation for exports, u_A , (Equation (6)):

$$u_A = z + 2.23(0.75p_w + 0.25p_{w-1}) - 1.26p_A + 1.71t - 82.78$$

In this equation z represents the volume of world exports, to which the Dutch exports were largely parallel. These latter are positively influenced by world market prices, p_w , as seen in the second term and negatively by their own price, p_A , as the third term shows. The elasticity of exports evaluated for 1934 with respect to p_w is 1.83, that with respect to p_A is -0.96 . The R^2 of this relation is 0.976.

The price of exports, p_A , is specified in Equation (4) by

$$p_A = 1.28p_w + 0.04(r'_A + 2l - 6t) - 32.18$$

where the first term reflects competition and the second term costs, with r'_A being the price of imported materials for consumer goods. A modern model builder would be worried by the lack of homogeneity of this equation. The R^2 is 0.991.

Finally, the value-volume conversion equation, (9),

$$U_A = u_A + 0.88p_A - 84.48$$

completes the block of export equations.

Imports

Tinbergen distinguishes between imports of finished goods for consumption, u'_A , those for investment, v'_A , imports of raw materials for the production of consumer goods, x'_A , and those for the production of investment goods, y'_A . Those four variables appear on the righthand side of Equations (8), (10), (12) and (13). Equation (8) has already been presented as the investment equation. Equation (10), with y'_A on the

righthand side, will be taken up when reviewing the labour market. Here we will consider Equations (12) and (13).

Equations (12) and (13) aim to explain the choice between home produced goods and imported goods as a function of their relative prices. Domestic production requires the import of raw materials and is considered to be proportional to that. In the case of choice between domestically produced and imported consumer goods, the basic relation is then

$$\ln(x'_A/u'_A) = \varepsilon_1 \ln(p/p'_A) + \text{constant} \quad (A)$$

with p being the cost of living and p'_A the price of u'_A , imported raw materials for the production of consumer goods. Linearizing this relation around the sample means yields

$$x'_A - (\bar{x}'_A/\bar{u}'_A)u'_A = \bar{x}'_A\varepsilon_1(p/\bar{p} - p'_A/\bar{p}'_A) + \text{constant} \quad (B)$$

Now \bar{x}'_A/\bar{u}'_A is about 0.71, while $\bar{p} = \bar{p}'_A = 100$. The equation in estimated form (12) is then

$$x'_A - 0.71u'_A = -0.42p + 0.39p'_A + 0.97t + 2.58$$

The separate coefficient of p and p'_A are justified by the lack of comparability of p , retail prices, also reflecting prices of imports and p'_A , wholesale prices. The implied value for the substitution elasticity ε_1 is about -1 . The R^2 of this equation is 0.781.

For the means of production the same line of reasoning is followed. The point of departure is

$$\ln(y'_A/v'_A) = \varepsilon_2 \ln(q/q'_A) + \text{constant} \quad (C)$$

where q is the price of means of production and q'_A that of imported raw materials for means of production. The sample means of y'_A and v'_A are equal: 13. Linearization of (C) around the sample means along the same lines as (B) leads to Tinbergen's Equation (13):

$$y'_A - v'_A = 0.86(q'_A - q) - t - 0.813$$

where the coefficient of the time trend has been fixed *a priori*. The implied value of ε_2 , the substitution elasticity, is -6.6 . This is substantially more than that for consumer goods. This might reflect the fact that the degree of substitutability between domestic and imported means of production is larger than that for domestic and imported consumer goods. The R^2 of Equation (13) is 0.690.

Import prices are all taken to be exogenous. Equations (21)–(24) are all linearized, converting

volumes into values, generating the values of the four types of imports distinguished:

$$U'_A = u'_A + 0.58p'_A - 58.89$$

$$V'_A = v'_A + 0.41q'_A - 12.99$$

$$X'_A = x'_A + 0.41v'_A - 41.55$$

$$Y'_A = y'_A + 0.13s'_A - 13.13$$

Total output

There are two equations with u , the volume of total output, on the righthand side: Equations (5) and (11). Equation (5)

$$u = u_A + u' - 2$$

seems to define total output, u , as the sum of exports, u_A , and of consumption, u' . The u series has been constructed from production indexes and from information about agricultural production independently of u_A and u' .

As a definition Equation (5) thus holds only approximately and an intercept is added to absorb the average discrepancy. It is to be noted that production of investment goods is not taken into account.

Equation (11) can be seen as a way to describe value-added in production:

$$u = 1.72u'_A + 4.35x'_A + 54.82$$

where u'_A is imports of finished consumer goods and x'_A imports of raw materials for the production of consumer goods. The coefficients of u'_A and x'_A have been estimated. The coefficient of u'_A implies that value-added is about $0.72/1.72 = 0.41$ of the value of those consumer goods which are already technically finished when entering the country. It is the margin for storage, distribution and profits. For consumer goods which are domestically produced the fraction of value-added is $3.35/4.35 = 0.77$ (clearly much larger). The R^2 of this relation is 0.855. We may note that it is implicitly assumed that exported goods are consumer goods only, which might not be unrealistic for the Dutch economy in the period considered. The model does not contain a price of total output or a value of total output.

Labour market

The labour component of value-added in production is described by Equation (9), which can also be written as Equation (9a):

$$a - b = 0.20u'_A + 0.98x'_A - 0.28t + 23.87$$

where we have on the left the difference between total employment, a , and employment in the investment industries, b . So $a - b$ is employment in the production of consumer goods, whether for local use or export. Obviously, less labour is needed to further process imported finished consumer goods, u'_A , than for the transformation of imported raw materials for consumer goods, x'_A . In the latter case $0.98/0.20 = 4.9$ more units of labour per unit of imports are needed than for the former. This rate comes close to that implied by Equation (11) for total value-added, namely $4.7 = 3.35/0.72$. It is not quite clear how Equation (9) was estimated. It seems that 0.20 was fixed and 0.98 was estimated. The R^2 of Equation (9) is 0.973.

Employment in investment industry, b , appears nowhere as a lefthand side variable. It appears in Equation (9), just reviewed, and in (10):

$$y'_A = 0.69b + 0.27t - 3.56$$

which seemingly explains the imports of materials needed for the production of investment goods, y'_A , but which can also be seen as the expression for the labour component of value-added in the production of investment goods. It is then implied that no labour is needed for the further processing of imported finished investment goods. The reciprocal of 0.69, 1.44, is comparable with the 0.98 of Equation (9) and indicates a higher labour intensity in the investment goods industry. The R^2 of this relation is 0.947.

Equation (1) is the wage formation equation:

$$l - l_{-1} = 0.27(p_{-1} - p_{-2}) + 0.16a - 16.28$$

It explains the changes in the wage rate, l , as a function of the changes in the cost of living, p , and total employment, a . Only a small part of the price change is compensated by wage change and even then with a lag of one year. Wages react immediately to a change in the employment situation. In view of the positive sign of the coefficient of total employment we may consider Equation (1) as reflecting supply behaviour.

Note that in this equation the *change* in the wages depends on the *change* in prices and on the *level* of employment. In this way, it resembles the Phillips-type wage equation. There is a problem, however. In the stationary state, if it exists for this model, $l = l_{-1}$ and $p_{-1} = p_{-2}$. Thus $a = 16.28/0.16 = 101.75$, independent of the values of the exogenous variables in the rest of the system. The long-run employment situation cannot be changed except by interfering with the wage formation process i.e. by changing Equation (1). This feature has serious consequences for the dynamics of the model which may not have been realized or

intended by Tinbergen. In the 1937 version of the model another wage equation was used which does allow for non-zero long-run effects on employment.

For the labour market the linearized volume-value conversion equation (14) is:

$$L = a + l - 100.2$$

where the coefficient of l equals 1 because of the choice of units.

Other income

The last equation not yet reviewed is the one for other or non-labour income, Z , also called profits. In current modelling practice non-labour income is usually determined as the difference between national income at factor costs and the wage bill. This is also its national accounting definition. The concept of non-labour income used by Tinbergen is wider because it also includes capital gains. This makes sense in his model where Z , with appropriate lags, drives investment and consumer spending. In accordance with this wider interpretation of profits Tinbergen calculates his Z series in an independent way. Its explanation also reflects the two aspects of his profits variable. One corresponds with the accounting identity aspect, the other with the capital gains component.

To start with the first, national income in current prices is implicitly defined by

$$U' + U_A + U_I - (U'_A + V'_A + X'_A + Y'_A) + I \quad (D)$$

where U_I is the value of the output of production goods and I is factor income received from abroad. The variable U_I does not appear explicitly in the Tinbergen model. Implicitly it is defined as

$$U_I = V'_A + U_{DI} \quad (E)$$

ie as the sum of imported, V'_A , and domestically produced, U_{DI} , means of production. Again this last variable does not explicitly appear in the model. It is approximated by

$$U_{DI} = u_{DI} + \bar{u}_{DI}q \quad (F)$$

with q being the price of means of production and u_{DI} the volume of domestically produced means of production. This latter variable is then explained as

$$u_{DI} = 3b \quad (G)$$

reflecting the observation that the contribution of labour, b , is one-third of the value of investment goods.

(In the 1937 model this is taken to be one-half.) On the basis of these assumptions $U_I - V'_A$ is in (D) replaced by

$$3b + (3\bar{b})q = 3b + 0.71q \quad (H)$$

After subtracting the wage bill from (D) we have what Tinbergen calls the static part of Z . The dynamic component consists of capital gains resulting from fluctuations in the prices of goods and securities. Domestic share prices are taken to develop parallel to Z , and foreign share prices parallel to the prices of raw materials in the world market. Since the profits are earned from the change in the prices of shares and goods, the dynamic part of Z is specified as

$$0.24(s'_A - s'_{A-1}) + 0.38(r'_A - r'_{A-1}) + 0.47(p'_A - p'_{A-1}) + 0.3(Z - Z_{-1}) \quad (I)$$

The last term is supposed to reflect capital gains from domestic share investments. The first three terms represent those gains from the change in the prices of raw materials for the production of investment goods, s'_A , those of raw materials used in the production of consumer goods, r'_A , and those of finished consumer goods, p'_A respectively. The coefficients in (I) have not been estimated, probably because of multicollinearity.

The sum of (I) and of (D), with $U_I - V'_A$ replaced by (H), constitutes Tinbergen's Equation (15), given in Table 2. In spite of it not having been estimated its R^2 equals 0.941. Equation (15) is of considerable importance for the dynamics of the model. In this connection the negative relation between Z and Z_{-1} is of interest. Equation (15) plays the role of the balance equation in current models, except that Z has no immediate feedback on most of the other variables in the model.

A first evaluation

The structural equations are based on economic reasoning. The consumption explanation distinguishes between the effects of labour and of non-labour income, a feature adopted by many later models. The same is true for allowing investment to depend on profits. One of the most striking features is the care with which the open nature of the Dutch economy has been modelled. Exports compete with the exports of other countries, imports compete with domestic production. This is also reflected in the formulation of the equations for the prices of consumer, producer and export goods: it is the unifying idea of the model. In terms of theoretical coherence the model is well ahead of the models of the late 1950s.

The absence of a data base with the type of coherence

offered by the system of national accounts appears to be a serious handicap. We have to admire the inventiveness of Tinbergen in circumventing the absence of data for concepts like investment, gross national product and so on, which are essential variables of current models.

The absence of taxes in the definition of (disposable) other income is striking and somewhat puzzling. No trace is found of government in general. The capital gains part of Z would have been an appropriate place to allow for the impact of monetary factors. The 1936 model is solidly non-money–non-financial. This was not a matter of principle because subsequent Tinbergen models for the USA and the UK contain monetary and financial blocks.

The model is linear in the variables and the coefficients, a virtual necessity for the time at which it originated. It required a number of linearizations which are neither conceptually nor empirically distorting.

The determination of the coefficients took place in three ways. Coefficients in linearized identities were calculated from sample means. A number of coefficients, usually characterizing production processes, have been fixed on the basis of information other than that coming from time series, more or less in the same way that current models make use of input–output information. Least squares has been employed in the other cases. Given the small sample size complete reliance on least squares would have been asking for trouble.

Today a sample period of only 11 years would raise many an eyebrow. As we found out, the point estimates are in a few cases rather sensitive to slight changes in the size of the sample. The original paper gives no clue about the nature of the trial and error process of which the published equations are the final result. The model was, however, not meant to discriminate between alternative approaches: it was meant as a descriptive tool. How it was in fact used is the subject of the following sections.

Solution

Given the linear nature of the model, it is a straightforward matter to obtain the reduced form of the model; but this was not the way Tinbergen solved it. As a first step, the exogenous variables were replaced by their assumed values. These, multiplied by the appropriate coefficients, were added to the intercepts. These intercepts were further modified according to the policy alternative considered. For instance, when increasing investment autonomously the intercept of Equation (8) is increased by 14 for three years. In the case of a devaluation all exogenous prices as well as

l , income from investment abroad, are increased. To take into account eventual reprisals the intercept of export equation (6), was reduced by 18.

The next step was to treat l , the wage rate, as an exogenous variable and to delete one equation, Equation (17), from the model. The model is then in almost fully recursive form with only two blocks, Equations (8) and (13) and Equations (2), (9), (11) and (12). This must have greatly facilitated calculations.

The model was then solved ie expressed in the wage rate, l , the lagged wage rate, l_{-1} , the lagged price difference, $p_{-1} - p_{-2}$, and Z_{-1} next to the intercepts. In this process an error was made. In Equation (15) U_A was incorrectly replaced by U'_A . Given the somewhat awkward notation such an error might be expected. In fact we found this error by making the same mistake when recalculating the Tinbergen results! In what follows we will use the correct solution.

Using three equations of this solution and Equations (16) and (17) of the original model Tinbergen formulated a five-equation recursive system for the endogenous variables that also appear with a lag in the model. This enabled him to quickly calculate a time path for each of these variables for each policy alternative; this was then used in the larger solved form to obtain a time path for the variables of interest such as employment and the balance of payments.

We will not reproduce this method of generating results. Instead we will exploit the linear structure of the model. By basing our calculations on the reported values of the structural coefficients rather than on already further processed values we avoid some of the rounding errors which were understandably present in the Tinbergen results.

Dynamic properties

The dynamic properties of a linear dynamic model can be derived from the part of the reduced form that links the endogenous variables, which also appear with a lag, to their lagged values. For the 1936 Tinbergen model this part is given in Table 3. There also the identity $p_{-1} = p_{-1}$ is added to obtain a square matrix.

The eigenvalues and eigenvectors of this matrix are given in Table 4. No complex parts of eigenvalues were found. Two eigenvalues were virtually zero. None of the eigenvalues is in absolute value larger than or equal to unity. The model is obviously damped. There is one large positive eigenvalue. As can be seen from the eigenvectors this is primarily associated with l , the wage rate. One glance at Equation (1) reveals the reason. It is formulated in the first difference in the wage rate. Although the high eigenvalue reflects slow convergence for l it may be presumed that it will not affect the

Table 3. Autoregressive part of reduced form.

	I_{-1}	P_{-1}	Z_{-1}	E_{-1}	E'_{-1}	P_{-2}
I	0.982	0.265	0.034	0.007	-0.028	-0.265
P	0.297	0.080	0.025	0.023	-0.087	-0.080
Z	-0.160	-0.043	0.079	0.234	-0.900	0.043
E	-0.077	-0.021	0.238	0.112	-0.432	0.021
E'	0.0	0.0	0.0	0.26	-1.0	0.0
P_{-1}	0.0	1.0	0.0	0.0	0.0	0.0

Table 4. Eigenvalues and eigenvectors.

Eigenvalues	0.972	-0.942	0.116	0.107
I	0.898	-0.014	0.222	0.239
P	0.268	0.046	0.098	0.096
Z	-0.176	0.629	0.191	0.133
E	-0.120	0.168	0.420	0.313
E'	-0.016	0.756	0.098	0.074
P_{-1}	0.275	-0.048	0.848	0.902

convergence for most of the other endogenous variables too much.

The negative eigenvalue is substantial too. It causes a two-period cycle with slow convergence. As can be read off from the eigenvector this is primarily true for Z , other income, and for E' , consumption out of other income. Going back to the structural Equation (15) the negative relation between Z and Z_{-1} is obvious. In the same way Equation (17) specifies a negative dependence of E' on E'_{-1} . In this case the two-period cycle may show up clearly only for Z and E' and far less for the other variables.

The two remaining non-zero eigenvalues are rather small. Apart from some variables the model is rather heavily damped. It is somewhat unfortunate that no pair of complex eigenvalues could be found corresponding to a business cycle of 8–11 years. For an economy like the Dutch the business cycle is mostly imported ie present in the exogenous variables of the system rather than endogenously generated by intertemporal interactions among the endogenous variables.

Multipliers

The dynamics of the model also express themselves in the values of the multipliers, in particular in those of the interim multipliers. Impact and interim multipliers are, of course, also of interest in their own right. In his policy application Tinbergen did not make use of them as such, although they are implicit in his dynamic simulations.

Among the many series of multipliers we will select those of autonomous investment and those of a devaluation. Among the endogenous variables the level of employment, a , the cost of living, p , and other

Table 5. Multipliers of autonomous investment.

Year	GDPQ	a	p	TBV	Z
a. Single one unit impulse in $t = 0$					
0	0.710	0.419	0.049	-0.650	0.995
1	0.421	0.225	0.059	-0.396	0.177
2	0.012	0.016	0.035	-0.069	-0.050
3	-0.007	-0.015	0.038	-0.031	0.026
4	-0.044	-0.017	0.030	-0.016	-0.063
5	-0.015	-0.018	0.035	-0.023	0.019
6	-0.041	-0.016	0.028	-0.015	-0.058
7	-0.015	-0.017	0.033	-0.021	0.016
8	-0.038	-0.015	0.027	-0.014	-0.052
9	-0.015	-0.016	0.031	-0.020	0.013
10	-0.036	-0.015	0.025	-0.014	-0.048
$\Sigma_{0,\infty}$	0.047	0.000	1.364	-1.848	0.348
b. Permanent increase by one unit from $t = 0$ on					
0	0.710	0.419	0.049	-0.650	0.995
1	1.131	0.644	0.108	-1.046	1.172
2	1.143	0.660	0.143	-1.115	1.122
3	1.136	0.645	0.181	-1.146	1.148
4	1.092	0.628	0.211	-1.162	1.085
5	1.077	0.610	0.246	-1.185	1.104
6	1.036	0.594	0.274	-1.200	1.046
7	1.021	0.577	0.307	-1.221	1.062
8	0.983	0.562	0.334	-1.235	1.010
9	0.968	0.546	0.365	-1.255	1.023
10	0.932	0.531	0.390	-1.269	0.975
∞	0.047	0.000	1.364	-1.848	0.348

income, Z , were chosen. To these were added two composite variables

$$GDPQ = u + 2y'_A - u'_A - x'_A$$

which is meant to represent gross domestic product in constant prices, and

$$TBV = U_A - (U'_A + V'_A + X'_A + Y'_A)$$

which expresses the trade balance as the difference between exports and imports of goods.

Autonomous investment is considered to be a unit shock in the disturbance of Equation (8), the investment equation. We consider two alternatives: a single unit shock in year zero and a permanent increase by one unit from year zero on. The results for the multipliers are given in Table 5. The interim multipliers are given

for 10 years. The last line of Table 5a contains the total multipliers. These exist because of the damped nature of the model. These also equal the interim multiplier for year ∞ of a sustained increase.

The first column of Table 5a comes close to the Keynesian investment multiplier. We may note that its impact value is less than one. We should realize that $GDPQ$ is value-added and that for an open economy this is not equal to production. The impact multiplier effect on imports (cf the impact multiplier on TBV) is 0.65. The impact multiplier on production is then 1.36.

Another way of approaching the same issue is to relate the value-added component of autonomous investment to the total value-added generated by that investment. With $v'_A + 3y'_A$ being investment, its value-added is

$$(v'_A + 3y'_A) - (v'_A + y'_A) = 2y'_A$$

Per unit of investment it is $2y'_A/(v'_A + 3y'_A)$. With v'_A and y'_A being roughly equal this ratio amounts to 0.5. Total value-added generated is 0.71. The multiplier is then $0.71/0.5 = 1.42$, a value in line with that of the multiplier for total production. The sequence of interim multipliers reflects the strong damping of the model, together with a two-year cycle. Activity levels quickly return to normal.

The impact on employment is rather modest and very transitory. We may note that the total multiplier is zero. This is the consequence of the specification of the equation for wage formation, Equation (1) – see the discussion of that equation above. Wages and prices are initially increased, wages more than the cost of living, p . They return very slowly to their original level, as was predictable from the high eigenvalue associated with wages. Exports are almost entirely unaffected, so the TBV column reflects the effect on imports. Consistent with the rise in production, imports increase initially to return quickly to their old levels. The impact on Z is rather high. In part this is due to the increase in value-added, in part to capital gains on shares in domestic industries. The two-year cycle arising from the large negative eigenvalue is obvious here. The main picture is that after two years there is little effect to be expected from an incidental increase in autonomous investment.

A sustained increase of the same size gives rise to the multipliers of Table 5b. The bottom line gives the change in the stationary state as the consequence of such an increase. The fact that, due to the specification of the wage equation, employment is not sensitive in the long run is confirmed here. It also means that in the long run activity levels will not be changed very much. The rise in the domestic wage and price levels

Table 6. Multipliers of foreign price increase (devaluation) (permanent increase by one unit from $t = 0$ on).

Year	GDPQ	a	p	TBV	Z
0	-0.021	0.016	0.161	0.272	3.087
1	1.663	0.834	0.333	-0.557	2.614
2	1.285	0.663	0.350	-0.338	2.293
3	1.282	0.620	0.394	-0.340	2.447
4	1.185	0.603	0.412	-0.337	2.247
5	1.215	0.583	0.454	-0.370	2.395
6	1.132	0.569	0.472	-0.373	2.218
7	1.158	0.551	0.512	-0.404	2.348
8	1.083	0.538	0.530	-0.408	2.189
9	1.105	0.521	0.567	-0.436	2.303
10	1.037	0.509	0.584	-0.440	2.161
∞	0.207	0.000	1.522	-0.999	1.608

will increase imports of finished goods, causing the trade balance to be less favourable.

The other example of multipliers will be those for a devaluation. The impulse here is a unit increase in all import prices, namely p'_A , q'_A , r'_A , s'_A , and the world price level, p_w . Table 6 gives the multipliers of a permanent shift in the value of the guilder. The last line presents the change in the stationary state values.

The impact of the devaluation in year 0 is rather small except for Z , other income. The devaluation hardly affects the volume of exports. Equation (6) specifies exports to depend on the difference between p_w , the world price level, and p_A , the export price level. Equation (4), however, links the latter closely to the former – Dutch exporters being price takers – so the difference is not allowed to become important. The increase in foreign prices relative to domestic prices causes a shift from imports of finished goods to imports of raw materials. This reduces imports somewhat and explains the positive effect on the trade balance (TBV) in year 0. The ensuing increase in value-added and domestic activity levels leads to higher imports which more than compensate the reduction. This explains the perverse J effect and illustrates the possibility that a devaluation does not necessarily lead to an improvement in the trade balance.

The effects of the devaluation on GDP and employment, a , are strong but taper off. This is again due to the insensitivity of employment in the long run, which forces activity levels to return to their original values. Prices adjust slowly to international ones. In the long run there is even an overadjustment. We should remember that price homogeneity is not built into the structural form. The initial increase in Z reflects capital gains and later on also the increase in value-added.

Policy implications

Tinbergen built his model to give advice on policy. He

used what we would today call a scenario approach. Under certain assumptions about exogenous variables and alternative values for policy instruments he generated a set of time paths for the endogenous variables, one for each policy alternative. These were compared with the no change case and the best one was selected.

A first alternative, P, was an increase in investment. Its model implementation amounted to adding a shift to Equation (8) of +14 during three consecutive years. The trade balance deteriorates moderately and the initial increase in employment vanishes quickly. These outcomes are consistent with our multipliers in Table 5a.

Alternative Q concerns trade protection by the restriction of imports of finished consumer goods. This is simulated by adding (not subtracting, as is incorrectly stated in the original memorandum) 15 to the righthand side of Equation (12), which explains the ratio of imports of raw materials for consumption to those of finished consumer goods. The increase of this ratio means an increase of domestic production of consumer goods at the cost of a reduction in the imports for those goods. The effects on employment are minor because of the resulting increase in prices, which reduces demand. The trade balance reacts very favourably.

A third alternative, R, is rationalization taking the form of an increase in labour productivity and a decrease in prices. To simulate the consequences, the righthand side of Equation (9), the equation explaining employment in the consumer goods industry, is reduced by 10, while on the righthand side of Equation (2), the cost of living equation, 5 is subtracted. The effect on the trade balance is very small, that on employment unfavourable. The price decrease is unable to generate enough demand to compensate for the loss of jobs due to the productivity increase. A variant of this scenario, R', only reduces prices. Because the reduction in prices also reduces non-labour income and hence investment, employment is still negatively affected but much less than for case R.

Alternative S is a wage reduction scenario, subtracting 5 on the righthand side of Equation (1), the wage formation equation, for one year only. It results in an initial increase in employment levels followed by a return to normal levels. The trade balance develops unfavourably. Tinbergen's results do not agree with ours, which show a minor improvement of the trade balance because of increased exports and reduced imports.

The devaluation scenario T includes not only an increase in exogenous import prices and the world market price by about 30% but also an increase by the same percentage in income from investment abroad. To take into account possible reprisals the

export equation, (6), was reduced by 18 on the righthand side, equivalent to a reduction of about 20%. More or less in accordance with our Table 6 Tinbergen finds that employment reacts favourably in the medium run and that the trade balance is affected unfavourably after year 0.

Among the various scenarios Tinbergen prefers the last one, that of devaluation. The initial position of the balance of payments is strong enough to absorb its adverse effects. The employment effects of a devaluation are clearly attractive. He suggests a devaluation of 20%. At the same time he pointed to the possibility of combining the various scenarios.

The meeting of the Economics and Statistics Association for which the paper was prepared was held on 24 October 1936. The paper itself was already available in September. On 27 September the Netherlands abandoned the gold parity of the guilder, the last country of the gold block to do so. The guilder was effectively devalued by 17–20%. Although Tinbergen's work was not the basis for the policy adopted, it was consistent with it.

Concluding remarks

The memorandum for the Dutch Association for Economics and Statistics was understandably in Dutch. To present it to a wider public a modified version of the 1936 model was published in English shortly afterwards (Tinbergen [12]). The 1937 model is very much like the 1936 model but incorporates some changes, mostly improvements.

Several other models were constructed before World War II. Radice [7] published a 6-equation quarterly model fitted to UK data for 1924–36. It represents a closed economy. Polak [6] built a multinational business cycle model using some of the Tinbergen estimation results. His model comprises the USA and seven European countries. Tinbergen himself constructed models for the USA and for the UK. The first was built when he and Polak were temporarily associated with the Economic Intelligence Service of the League of Nations. It consists of 48 equations and contains a monetary and financial submodel of 9 equations. It was fitted to annual data for 1919–32. Tinbergen's UK model counts 39 equations also including a 10-equation block for the money and capital market. It was fitted to data for 1870–1914 and was thus a historical exercise. It was published, after considerable delay, in 1951.

The period 1936–39 was extremely fruitful; but with the outbreak of war began a period of consolidation. The next ten years were barren as far as the construction of models is concerned. However, data bases were improved and methodological issues were tackled, so

that when model building was taken up again the initial conditions were much more favourable than when Tinbergen was working.

We look back at the Tinbergen 1936 model with mixed feelings. On the one hand we note certain shortcomings or unnecessarily complicated procedures. The short sample and the relatively low quality of the data rank high among the weaker points of the model. On the other hand, the realization that the 1936 model constitutes the first empirically verified dynamic macroeconomic model for an open economy fills one with respect for its builder. If we furthermore realize that it was indeed able to generate answers for the problems of the day this respect grows. Among the later models there are many with weaker theoretical foundations, smaller scope and less operationality. The modelling profession has learned much since 1936, but perhaps less than it thinks.

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Appendix 1

Re-estimating the structural coefficients

The structural coefficients of the 1936 model have been estimated by a variant of least squares which divides the regression coefficients by the correlation coefficient. In view of the absence of calculating equipment, computational short cuts have been used. In this appendix we compare the structural coefficients of the 1936 memorandum with our least squares results and with those of consistent instrumental variables estimation.

Fourteen equations were estimated by least squares. The point estimates of the structural coefficients are presented in Tables 7-20. On the first line are the coefficients as reported by Tinbergen (TB), except that the intercept and the coefficient of determination, R^2 have been calculated by us, using the original data. On the second line the results of the application of least squares (LS) are given. Standard

errors can be found in parentheses below the coefficients. The standard error of regression, SE, and the Durbin-Watson statistic, DW, are given. The latter is primarily used as a measure of residual autocorrelation, not as a test statistic. The standard errors have been derived under the assumption of no autocorrelation of the disturbance terms.

The least squares method may be inconsistent because of the simultaneous determination of the endogenous variables, measurement errors or because of the presence of lagged endogenous variables among the regressors when the disturbances are autocorrelated. In principle, the method of instrumental variables (IV) with the exogenous variables as instruments is a consistent procedure. There are nine exogenous variables in the model of which four also occur with a lag. Given a mere eleven observations - for Equation

Table 7. Equation (1), dependent variable: $I - I_{-1}$.

Method	$p - p_{-1}$	a	Intercept	R^2	SE	DW
TB	0.27	0.16	-16.28	0.897		
LS	0.264 (0.077)	0.162 (0.037)	-16.52 (3.82)	0.897	0.82	1.08
IV	0.321 (0.093)	0.149 (0.041)	-15.05 (4.32)	0.890	0.84	1.43

Table 8. Equation (2), dependent variable: p .

Method	p_A	$r_A' + 2I - 6t$	u	Intercept	R^2	SE	DW
TB	0.04	0.15	0.08	24.24	0.978		
LS	0.148 (0.128)	0.091 (0.063)	-0.005 (0.045)	59.51 (21.48)	0.984	1.30	1.98
IV	0.100 (0.139)	0.115 (0.069)	0.012 (0.049)	51.66 (23.36)	0.983	1.32	2.08

Table 9. Equation (3), dependent variable: q .

Method	q_A	$s_A' + 2I - 6t$	t	Intercept	R^2	SE	DW
TB	0.74	0.16	0.16	-22.47	0.987		
LS	0.643 (0.187)	0.197 (0.049)	0.552 (0.592)	-23.88 (15.61)	0.990	1.69	3.24
IV1	0.658 (0.188)	0.190 (0.050)	0.509 (0.594)	-23.35 (15.64)	0.990	1.69	3.19

Table 10. Equation (4), dependent variable: p_A .

Method	p_w	$r_A' + 2I - 6t$	Intercept	R^2	SE	DW
TB	1.28	0.04	-32.18	0.991		
LS	1.187 (0.225)	0.064 (0.065)	-30.63 (4.69)	0.991	2.46	1.22
IV	1.179 (0.226)	0.066 (0.065)	-30.59 (4.69)	0.991	2.46	1.23

Table 11. Equation (6), dependent variable: u_A .

Method	z	$0.75 p_w + 0.25 p_{w-1}$	p_A	t	Intercept	R^2	SE	DW
TB	1	2.23	-1.26	1.71	-82.76	0.976		
LS	1 (*)	2.191 (0.535)	-1.227 (0.389)	1.677 (0.586)	-82.36 (15.04)	0.979	2.51	2.29
IV	1 (*)	2.179 (0.713)	-1.215 (0.522)	1.705 (0.637)	-82.47 (17.99)	0.977	2.51	2.28

Table 12. Equation (8), dependent variable: $v'_A + 3y'_A$.

Method	Z_{-1}	t	Intercept	R^2	SE	DW
TB	0.51	2.93	-48.10	0.887		
LS	0.474 (0.053)	3.610 (0.374)	-41.05 (10.48)	0.937	3.47	1.47
IV	0.477 (0.054)	3.620 (0.375)	-41.65 (10.65)	0.937	3.47	1.48

Table 13. Equation (9), dependent variable: a .

Method	b	u'_A	x'_A	t	Intercept	R^2	SE	DW
TB	1	0.20	0.98	-0.28	23.87	0.973		
LS	1 (*)	0.20 (*)	1.117 (0.113)	-0.502 (0.168)	18.22 (4.68)	0.978	1.40	2.94
IV	1 (*)	0.20 (*)	1.150 (0.115)	-0.532 (0.170)	16.84 (4.76)	0.978	1.41	3.07

Table 14. Equation (10), dependent variable: y'_A .

Method	b	t	Intercept	R^2	SE	DW
TB	0.69	0.27	-3.56	0.941		
LS	0.669 (0.070)	0.256 (0.067)	-3.012 (1.683)	0.948	0.66	1.11
IV	0.681 (0.073)	0.253 (0.067)	-3.285 (1.754)	0.948	0.66	1.11

Table 15. Equation (11), dependent variable: u .

Method	u'_A	x'_A	Intercept	R^2	SE	DW
TB	1.72	4.35	54.82	0.855		
LS	1.933 (0.865)	3.748 (0.946)	67.14 (41.23)	0.862	11.72	1.54
IV	1.907 (0.912)	3.846 (0.978)	64.65 (42.08)	0.862	11.73	1.66

Table 16. Equation (12), dependent variable: $x'_A - 0.71u'_A$.

Method	p	p'_A	t	Intercept	R^2	SE	DW
TB	-0.42	0.39	0.97	2.579	0.781		
LS	-0.094 (0.545)	0.297 (0.147)	1.279 (0.620)	-20.75 (41.24)	0.797	2.16	3.21
IV	-0.367 (0.636)	0.366 (0.168)	1.028 (0.693)	-0.253 (47.99)	0.790	2.20	3.27

Table 17. Equation (13), dependent variable: $y'_A - v'_A$.

Method	$q'_A - q$	t	Intercept	R^2	SE	DW
TB	0.86	-1	-0.813	0.690		
LS	0.799 (0.101)	-1 (*)	-0.791 (0.396)	0.702	1.31	2.91
IV2	0.858 (0.111)	-1 (*)	-0.812 (0.403)	0.691	1.33	3.09

Table 18. Equation (16), dependent variable: E .

Method	Z	Z_{-1}	Intercept	R^2	SE	DW
TB	0.48	0.20	52.47	0.991		
LS	0.472 (0.033)	0.287 (0.038)	46.93 (4.36)	0.993	1.62	1.19
IV	0.471 (0.035)	0.238 (0.040)	46.87 (4.40)	0.993	1.62	1.19

Table 19. Equation (17), dependent variable: $E' + E'_{-1}$.

Method	E_{-1}	t	Intercept	R^2	SE	DW
TB	0.26	-1.8	224.07	0.939		
LS	0.229 (0.054)	-1.793 (0.274)	229.9 (10.27)	0.942	2.18	2.07
IV	0.232 (0.054)	-1.785 (0.274)	229.2 (10.32)	0.942	2.18	2.06

Table 20. Equation (18), dependent variable: $E'' + E''_{-1}$.

Method	E_{-1}	t	Intercept	R^2	SE	DW
TB	1.74	1.74	-261.03	0.862		
LS	1.513 (0.214)	1.751 (1.120)	-219.0 (40.34)	0.888	9.18	1.37
IV	1.533 (0.216)	1.818 (1.125)	-222.9 (40.74)	0.888	9.18	1.39

(17) only ten – a selection has to be made. Since four of the exogenous variables are import prices we used only two of these. All lags were omitted. For most of the equations the set of instruments consisted of p'_A, r'_A, z, I, t and the constant. In the case of Equation (3), q'_A and s'_A appear among the regressors. They have there replaced p'_A and r'_A in the set of instruments for efficiency reasons. The use of IV with this set of instruments is indicated by IV1. For Equation (13), where q'_A is part of the regressors, this variable replaces p'_A in the original set of instruments, which is indicated by IV2.

From the 14 tables it may be concluded that the R^2 are fairly high, with a few exceptions. The standard errors of regression are for the prices at most 2.5% of the sample average of the corresponding dependent variable. For the volume and value equations they are less than 1% of the sample average of total output, u , except for Equations (11) (the one for u) and (18).

There are an unusual number of large values for the DW statistic. These always occur when the trend term is among the regressors. The role of this trend is to detrend all series.

This detrending might generate negative autocorrelation in the resulting series.

In nearly all cases the Tinbergen values for the regression coefficients are similar to the LS and the IV results. Differences may be due to the division by R or to a lower degree of computational precision. These appear not to be substantial.

Appendix 2

Consistency tests

The 1936 model is not a fully recursive model and the data used are surely not without error (two reasons for LS to be an inconsistent estimator). Moreover, there are lagged endogenous variables on the righthand side of several equations, while autocorrelated disturbances cannot be ruled out. This is another reason for inconsistency of LS.

Tinbergen used LS with the regression coefficients divided by the square root of the coefficient of determination. We have not been able to generate exactly the same results. However, as can be seen from Appendix 1, the difference between our LS results and the Tinbergen coefficients are in most cases not very important. Appendix 1 also reports the results of IV estimation, using a selection of the exogenous variables as instruments. Under suitable conditions this procedure is consistent or, to offer a more prudent formulation, less inconsistent than LS. We may note that the IV and the Tinbergen coefficients and the IV and the LS results are rather similar. Can we assess their difference statistically? When inconsistency would show up in such a difference, its significance can be seen as an indication of (serious) inconsistency. The absence of significance is not, of course, a rejection of inconsistency. It simply means that serious inconsistency could not be found. One reason for that could be that the smallness of the sample causes confidence regions to be so wide that hardly any null hypothesis can be rejected.

We will report here on two tests, applied to each estimated equation separately. The first one is a procedure proposed by Sargan [8], which tests whether the LS estimates lie outside the confidence region with the IV estimator as its centre. Here we will apply the test to the Tinbergen values. Note that we have estimated the intercept, which therefore should not be used in the comparison. The test basically uses as the null hypothesis that the Tinbergen values are the correct ones. Let b_T be the vector of Tinbergen values and b_I those estimated by the IV procedure. Let \bar{b}_T and \bar{b}_I be those vectors without intercepts. Moreover, let $V(\bar{b}_I)$ be the estimated covariance matrix of the IV estimator. Our Sargan test statistic is then

$$(\bar{b}_T - \bar{b}_I)' [V(\bar{b}_I)]^{-1} (\bar{b}_T - \bar{b}_I)$$

which under the null hypothesis is (asymptotically) distributed as central χ^2 with $k-1$ degrees of freedom, where k is the number of estimated coefficients in the equation.

The other test is a Hausman [5] test. It tests the significance of the difference between b_I and b_L , being the least squares estimator. Let $V(b_I)$ be the estimated covariance

The LS and the IV results are rather close. Can we consider this as an indication of the absence of least squares inconsistencies? The answer to this question is more formally approached in Appendix 2. Here it suffices to point out that (in)consistency is a large sample property and that our sample is extremely small.

Table 21. Values of consistency test statistics.

Equation	Sargan test statistic	Hausman test statistic
1	0.312 (2)	2.029 (2)
2	8.167 (3)	2.714 (2)
3	1.932 (3)	0.960 (1)
4	0.224 (2)	0.103 (1)
5	0.123 (3)	0.523 (2)
6	6.209 (2)	0.104 (1)
9	2.721 (2)	3.366 (1)
10	0.117 (2)	0.318 (1)
11	0.290 (2)	0.766 (2)
12	0.170 (3)	0.775 (1)
13	0.000 (1)	2.059 (1)
16	1.750 (2)	0.011 (2)
17	0.373 (2)	0.401 (1)
18	0.568 (2)	0.499 (1)

matrix of the full IV estimator and $V(b_I)$ that for the LS estimator. To obtain those covariance matrices the same estimate for the disturbance variance has been used, namely that of the IV application. The Hausman test statistic is then

$$(b_L - b_I)' [V(b_I) - V(b_L)]^+ (b_L - b_I)$$

The difference between the two covariance matrices does not have full rank when the exogenous variables in the equation are part of the set of instruments, as is always the case in our application. This explains why the generalized inverse has been taken. Under the null hypothesis of consistency of LS, this test statistic is distributed as central χ^2 , with the number of endogenous variables on the righthand side of the equation as the number of degrees of freedom.

In Table 21 the values of the two test statistics are given with the relevant number of degrees of freedom in parentheses. The 95% critical values are for $\chi^2(1)$ 3.841, $\chi^2(2)$ 5.991 and $\chi^2(3)$ 7.815 respectively. The Hausman test statistic is always less than the 95% critical value. The inconsistency of the LS estimator has not been detected for this model and these data. The Sargan test statistic exceeds twice its 95% critical value for Equations (2), the equation for the cost of living, and (6), the investment equation. As can be seen from Table 8 and 12 in those cases also our LS results differ strongly from the Tinbergen values. This suggests that the difference is due to computational aspects rather than to statistical properties.

In conclusion we may say that our experiments do not indicate that least squares inconsistency has caused serious problems.

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